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Software Defined 5G Converged Mobile Access Networks: Energy Efficiency Considerations

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Abstract: Software Defined Mobile Networks and Software Defined Access Networks bring programmability principle into mobile and optical domains. In this work we propose an integrated control approach and show the benefit in terms of energy efficiency.

1. Introduction

Softwarization of networks represents a key technology towards fifth generation (5G) mobile networks. Logically centralized control and programmability principles will enable to govern the huge traffic demands expected for 5G. The idea of separation between control and data planes of Software Defined Networks (SDNs) has been extended to both Mobile and Optical domains.

Software Defined Mobile Networks (SDMNs) could enhance the performance of Core and Radio Access Networks through advanced joint resource allocation, spectrum and mobility management, and cooperation among heterogeneous networks [1]. Software Defined Access (SDA) has been proposed for the optical domain with special focus on the integration between Access and Aggregation networks [2].

Software Defined Access can bring several additional advantages to the end-to-end network segment such as enhanced resource utilization with guaranteed Quality of Service (QoS), reduced operational expenditure (OPEX) thanks to remote and programmable operations, flexibility in end-to-end networking, improved scalability and resiliency. Moreover, it enables the implementation of dynamic wavelength and bandwidth allocation (DWBA) capabilities in Passive Optical Networks (PONs) and aggregation capabilities in metro networks [3].

One of the main challenges in 5G is the centralization of evolved NodeBs (eNB) functionalities. A popular approach is to split the functionalities of eNBs between Central Unit (CU) and Distributed Units (DUs). 3GPP proposed 10 possible functional splits each of them characterized by different bandwidth and maximum latency requirements between the CU and the DUs [4]. In general, a huge number of functionalities centralized at CU requires high data rate and low latency budget. On the other hand, higher centralization enables higher scalability and more efficient radio resource management possibilities.

Fronthaul latency and bandwidth requirements call for the optimization of PON DWBA schemes. In [5, 6], a traditional Dynamic Bandwidth Allocation (DBA) scheme based on the mechanism of the REPORT-GATE messages exchange showed to reach 1 *ms* latency which is still incompatible with fronthaul requirements. In [5], a mobile DBA scheme for TDM-PON which calculates bandwidth allocation based on the mobile scheduling information of the Base Band Units (BBUs) has been proposed. It allows to reach a latency lower than 50 μs, however, it requires the development of a new ad-hoc interface between PON and the BBU. In [6], Fixed Bandwidth Allocation (FBA) is shown to guarantee 35 μs latency. Here, the bandwidth allocation is based on statistical traffic analysis to overcome the inefficiency of default bandwidth utilization compared to FBA.

Another important aspect in PON based access networks is *energy efficiency*, which indeed impacts on the OPEX. [7] provides a model to analyze energy savings in TWDM-PONs by exploiting multiple wavelengths. In [8], an energy evaluation for Cloud Radio Access Networks (C-RAN) employing TDM-PON as fronthaul has been provided, and a comparison between C-RAN and 10G-EPON-LTE architecture was presented. PON based fronthauling is shown to reduce energy consumption of about 40% in one day. However, the software-based integration of access and metro network is yet to be studied.

In this work we propose to leverage SDA and SDMN integration to dynamically configure FBA for PON fronthauling based on the number of active DUs in the access networks. The results show that, in low-load hours, it is useful to consolidate CU and reduce the number of DUs, hence, some of the active DUs and wavelengths can be switched off, resulting in energy savings. We consider NG-PON2 and show energy efficiency advantages adopting the model proposed in [7] for power consumption calculations.

2. System Model

In our design we consider the architecture shown in Fig. 1 (a) where a Macrocell is overlapped by several small cells. Each cell site is equipped with a DU connected to a CU at the central office location. The fronthaul segment is implemented through a TWDM-PON, therefore each DU is equipped with an Optical Network Unit (ONU). The PON is under control of an SDA Controller which interacts with agents at the Optical Line Terminations (OLTs). The SDA controller is in charge of taking decisions related to bandwidth and wavelength assignment, wavelengths activation, flow modification and integrated QoS with metro network. The mobile network is under the control of an SDMN Controller, which takes Radio Resource Management decisions, DUs activation/deactivation, centralized management and cooperation among DUs.

FBA represents a feasible solution to guarantee low latency and assured bandwidth in the fronthaul segment. However, it allocates bandwidth even when it is not utilized by the DUs falling therefore in inefficient bandwidth utilization. In this work we propose a Software Defined WBA (SD-WBA) that integrates SDMN and SDA. The proposed approach allocates bandwidth and wavelengths in the PON only when DUs are activated and deallocate bandwidth when DUs are deactivated.

As shown in Fig. 1 (b), once the SDMN controller detects a load variation in the mobile network that requires a new DU activation, it notifies the SDA controller. The SDA controller interacts with the OLT that, in turn, acknowledges the SDA controller if enough bandwidth is available to serve the new fronthaul, and if needed activates a new wavelength. Moreover, the OLT sends a grant message to the interested ONU.

When the SDMN controller receives acknowledgment from SDA controller about fronthaul segment feasibility, the mobile procedure for cell activation takes place and the fronthaul traffic can start to flow.

3. Performance Evaluation and Results

In our reference scenario a Macrocell is overlapped by 11 small cells (for reader's convenience, in Fig. 1 (a) only 6 small cells are shown). The fronthaul segment is implemented through NG-PON2 that is a TWDM-PON with four wavelengths pairs. Downstream wavelengths support 10 Gbps data rate while upstream wavelengths support 2.5 Gbps. Regarding functional split between DU and CU, we focus on option 7a Intra-PHY split defined in [4]. It requires 666 Mbps upstream bandwidth and a maximum latency of 250 μs for LTE 20MHz MIMO 2x2. The analytical evaluation of the considered scheme is perfomed by using MATLAB environment.

We assume the Macrocell serving a business area characterized by the time-variant traffic loads illustrated in Fig. 2 (a) [9]. The SDMN controller guarantees that the Macrocell DU is always active and activates/deactivates small cells DUs according to the load of the Macrocell. Fig. 2 (b) shows the number of active DUs during the day corresponding the time-variant traffic loads. Since each new fronthaul segment requires 666 Mbps and an upstream wavelength supports 2.5 Gbps we can accommodate a maximum of 3 fronthaul segments per each wavelength. The remaining bandwidth can be utilized for other services such as Fibre to the Home (FTTH), business with fixed connectivity and Internet of Things (IoT).

We adopt the model illustrated in [7] to calculate the power consumption related to multi-wavelengths components. In FBA approach the bandwidth is constantly reserved to all the 12 fronthaul segments. This implies that all the wavelengths are always active and the maximum power consumption is utilized. We compare FBA power consumption

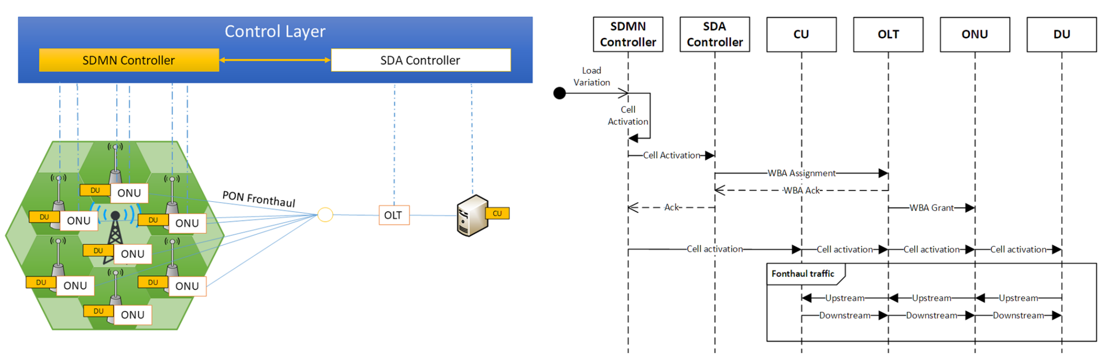

Fig. 1: (a) System Model; (b) Wavelength and Bandwidth Allocation Sequence Diagram

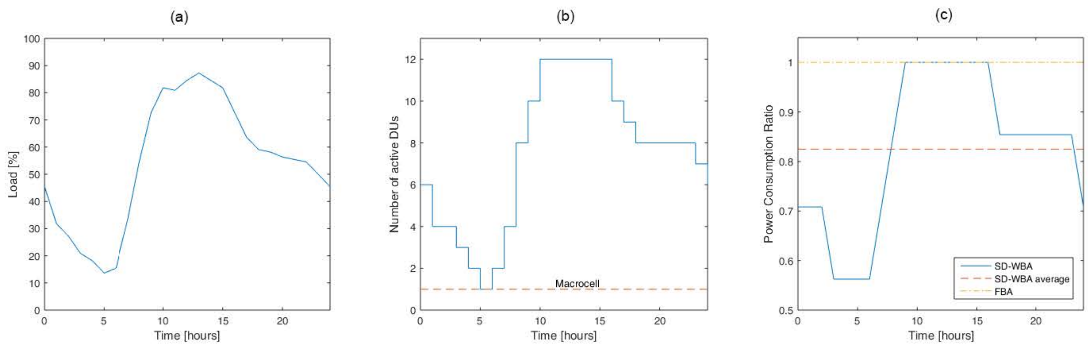

Fig. 2: (a) Macrocell area load; (b) Number of active DUs; (c) Wavelenghts power consumption normalized to FBA power consumption

with SD-WBA approach. Fig. 2 (c) illustrates the ratio between wavelengths related power consumption in both FBA and SD-WBA approach. It can be noticed that SD-WBA approach allows to reduce power consumption up to 55% during night hours when the load is low and only the Macrocell DU is active. In average, SD-WBA power consumption is 18% lower than in FBA case.

4. Conclusion

We proposed to integrate SDMN and SDA control for optimal WBA in TWDM-PON fronthauling. We illustrated a wavelength and bandwidth allocation mechanism based on cell activation and deactivation. Energy efficiency considerations are provided. Results show that SD-WBA approach allows to reduce up to 55% power consumption with a total energy saving of 18%.

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